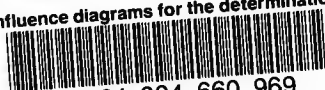


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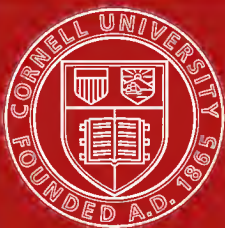
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# INFLUENCE DIAGRAMS

FOR THE

## DETERMINATION OF MAXIMUM MOMENTS IN TRUSSES AND BEAMS

BY  
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## PREFACE

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THE use of influence lines for the determination of maximum moments and criterions for wheel loads is presented in many modern text books.

The object of these few pages is to bring attention to the fact that for loads on all ordinary trusses, the influence diagrams for bending moments are drawn by following a single simple rule, and that the diagrams so constructed require no computations for their direct application. In addition to this the influence diagrams for loads on continuous trusses, cantilever trusses and arches are shown to be based upon the one general diagram for simple trusses.

While the diagrams, as a rule, are constructed for moments yet they can be as easily drawn for stresses or even areas of truss members.

The use of the influence diagrams in the determination of criterions for the positions of wheel loads which produce maximums is explained and shown to be very simple.

M. A. H.

DECEMBER, 1913.



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### DEFINITION

An influence diagram is one which shows the effect of a unit load moving across a structure upon any function of the structure for any position of the load.



# INFLUENCE DIAGRAMS FOR THE DETERMINATION OF MAXIMUM MOMENTS

---

## CHAPTER I

### SIMPLE TRUSSES \*

**An Influence Line** for the bending moments at the center of moments for any member of a truss on two supports for vertical loads can be constructed by a method which is perfectly general in its application. The truss may be of any shape, and the loads may be applied to either the upper- or lower-chord joints.

A section is passed through the truss, in the usual manner, cutting the member whose influence line is to be drawn. This section must evidently also cut a stringer in the panel of the truss containing the cut loaded chord. Let:

$d$  = the horizontal projection of the length of the stringer which is cut by the section. This stringer will be called the **cut stringer**.

$b$  = the horizontal distance from the left support of the truss to the left end of the *cut stringer*.

\* See "General Method for Drawing Influence Lines for Stress in Simple Trusses," by Malverd A. Howe. *Engineering News*, June 12, 1913.

$s$  = the horizontal distance from the left support of the truss to the center of moments.  $s$  will be considered positive when measured to the right.

$h$  = the vertical distance, at the *left* end of the *cut stringer*, between the two chord members which are cut by the section.

$h'$  = the vertical distance between the same chords at the *right* end of the *cut stringer*.

**The General Rule** for drawing the influence line is as follows:

(a) Through any point  $A$  (refer to Fig. 1; the other figures are lettered correspondingly) in a vertical line passing through the center of moments, draw a horizontal line cutting the vertical line through the left support of the truss at  $C$  and the vertical line through the right support at  $B$ .

(b) From  $C$ , at *any convenient scale*, lay off vertically downward the distance  $CD = AC = s$ , and connect  $B$  and  $D$  by a straight line.

(c) Through  $A$  and  $D$  draw a straight line and prolong it until it cuts the vertical line drawn through the *left* end of the *cut stringer* at  $E$ .

(d) Draw a vertical line through the *right* end of the *cut stringer*, intersecting the line  $ACB$  at  $F$ , and connect  $E$  and  $F$  by a right line.

(e) The polygon  $DEFBD$  contains the influence line sought; the ordinates between the line  $DEFB$  and the line  $DB$  are the respective moments for unit loads on the truss vertically above them, i.e., the lines  $ef = z_1$ ,  $rc = z_2$ ,  $gk = z_3$ , are proportional to the stresses produced by loads of one pound at  $W_1$ ,  $W_2$  and  $W_3$ , respectively. The ordinates are measured at the scale used in laying off the distance  $CD = s$ .

The application of the above rule to several forms of trusses will now be considered.

**Diagonal of Pratt Truss with Inclined Top Chord.**— Fig. 1 shows this truss and the influence diagram for the member  $UL'$ . The shaded area is the influence diagram.

To prove the construction correct, let the angles made with  $AB$  by the lines  $AE$ ,  $EF$  and  $DB$  be respectively  $\theta_1$ ,  $\theta_2$  and  $\theta_3$ , and let the distance from the left support of the truss to the unit load be, in general, represented by

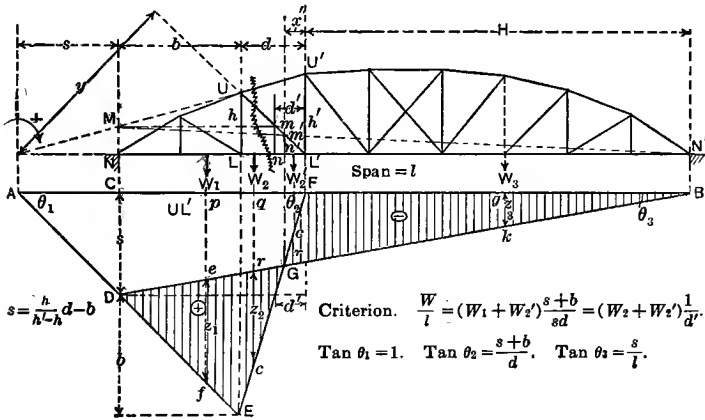


FIG. 1.

*a.* While the load  $W_1$  is to the left of the *cut stringer*, or to the left of the vertical through  $E$ , the moment is:

$$M_s = -W_1 \frac{l-a_1}{l} s + W_1 (s+a_1) = -W_1 (l-a_1) \frac{s}{l} + W_1 (s+a_1) \frac{1}{1}, \quad (1)$$

or

$$M_s = -W_1 (l-a_1) \tan \theta_3 + W_1 (s+a_1) \tan \theta_1, \quad (2)$$

$$= W_1 (-pe + fp) = W_1 (+ef). \quad (3)$$

Since the resultant moment is positive, the moment  $UL'(y)$  is negative and therefore  $UL'$  is in compression.

If the load,  $W_2$  (or  $W_2'$ ) is on the *cut stringer*, or between the verticals through  $E$  and  $F$ , the moment is, for  $W_2$ ,

$$M_s = -W_2 \frac{l-a_2}{l} s + W_2 \frac{b+d-a_2}{d} (s+b) \quad . \quad . \quad (4)$$

$$= -W_2(l-a_2) \frac{s}{l} + W_2(b+d-a_2) \frac{s+b}{d}, \quad . \quad . \quad (5)$$

or

$$M_s = -W_2(l-a_2) \tan \theta_3 + W_2(b+d-a_2) \tan \theta_2; \quad (6)$$

and hence

$$M_s = W_2(-qr + qc) = W_2(+rc) \quad . \quad . \quad . \quad . \quad (7)$$

Since the resultant moment is positive the stress in  $UL'$  is compressive.

For the load  $W_2'$

$$M_s = W_2'(-rc), \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and  $UL'$  is in tension.

When the load is between the *cut stringer* and the right support of the truss, the moment is:

$$M_s = -W_3 \frac{l-a_3}{l} s = -W_3(l-a_3) \frac{s}{l} = -W_3(l-a_3) \tan \theta_3,$$

or

$$M_s = W_3(-gk), \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and the member  $UL'$  is in tension.

If the diagonal inclines in the opposite direction, as in a Howe truss, the construction of the influence diagram remains unchanged but the character of the stress is reversed.

**Load-position for Maximum Moment.** — For uniform loads, the influence diagram *DEGFB* at once indicates the portions of the span which are loaded to produce like moments and hence maximum stresses.

The criterion for giving the position of wheel loads producing the maximum moment is readily found from the influence diagram. For cases which usually occur in practice, the portion of the span on the left of the *cut stringer* may be considered as unloaded. For convenience  $W_2$  is assumed to represent all of the loads between the verticals through *E* and *G* concentrated at their center of gravity,  $W_2'$  all of the loads between the verticals through *G* and *F*, and  $W_3$  all of the loads between the verticals through *F* and *B*. Let  $z_2$ ,  $z_2'$  and  $z_3$ , be the ordinates of the influence diagram directly below the wheel loads  $W_2$ ,  $W_2'$  and  $W_3$ . The moment is

$$M_s = W_2(z_2) - W_2'(z_2') - W_3(z_3). \quad . \quad . \quad . \quad (10)$$

If the loads move toward the left a distance  $\delta x$ , and no additional load comes on the span from the right and no load moves off the left end of the *cut stringer*, the moment becomes:

$$\begin{aligned} M_s' &= W_2(z_2 - \delta x \tan \theta_3 + \delta x \tan \theta_2) \\ &\quad - W_2'(z_2' + \delta x \tan \theta_3 - \delta x \tan \theta_2) - W_3(z_3 + \delta x \tan \theta_3). \end{aligned} \quad (11)$$

The difference between these moments is,

$$\begin{aligned} M_s' - M_s &= \delta M_s = W_2(-\tan \theta_3 + \tan \theta_2) \delta x \\ &\quad - W_2'(\tan \theta_3 - \tan \theta_2) \delta x - W_3(\tan \theta_3) \delta x. \end{aligned} \quad (12)$$

Dividing through by  $\delta x$  and placing  $\frac{\delta M_s}{\delta x} = 0$ ,

$$\frac{\delta M_s}{\delta x} = (W_2 + W_2' + W_3)(-\tan \theta_3) + (W_2 + W_2')(\tan \theta_2) = 0 \quad (13)$$

$$= -(W)\frac{s}{l} + (W_2 + W_2')\frac{s+b}{d} = 0, \quad \dots \dots \dots (14)$$

where  $W = W_2 + W_2' + W_3$  = the total load on the span.

Therefore, from equation (14), the desired criterion is

$$\frac{W}{l} = (W_2 + W_2')\frac{s+b}{sd} = \frac{W_2 + W_2'}{d'}, \quad \dots \dots (15)$$

where

$$\frac{1}{d'} = \frac{s+b}{sd}, \quad \text{or} \quad d' = \frac{d}{s+b}s = \frac{s}{\tan \theta_2} \dots \dots (16)$$

The value of  $d'$  is found graphically from the influence diagram by drawing a line through  $D$  parallel to  $CB$  until it cuts the vertical line through  $F$ , then  $d'$  is the distance indicated in the figure (Fig. 1 and those which follow). This value may also be found graphically without drawing the influence diagram by simply drawing in the truss diagram the line  $Mm$  parallel to the *bottom cut chord*  $LL'$  and prolonging it until it cuts a diagonal line drawn from the intersection of the cut top chord and a vertical through the left end of the *cut stringer* to the intersection of the cut bottom chord and the vertical through the right end of the *cut stringer*. This point is indicated by the letter  $m$  in the figure. The horizontal distance of this point  $m$  from

the vertical through the right end of the *cut stringer* is the value of  $d'$ . This is easily shown as follows: Fig. 1.

$$mn : h :: d' : d, \quad \text{or} \quad d' = \frac{d}{h} mn = \frac{d}{h} MN; \quad . \quad . \quad (17)$$

but

$$MN : s :: h : s + b, \quad \text{or} \quad MN = \frac{s}{s + b} h; \quad . \quad . \quad . \quad (18)$$

therefore

$$d' = \frac{s}{s + b} d = \frac{d}{s + b} s, \quad . \quad . \quad . \quad . \quad (19)$$

which is the value given in (16).

**Neutral Point.**—The position of a load which produces no stress in the web member  $UL'$  is indicated by the point  $G$  in the influence diagram, Fig. 1, since a load in the truss immediately above  $G$  produces no stress in the member as shown by a zero ordinate in the influence diagram. The point  $m'$  shown in the truss diagram is directly above  $G$ . This point is located by the intersection of the line  $MN'$  and the diagonal drawn as explained in determining  $d'$ . Let  $x'$  be the horizontal distance from  $m'$  to the vertical through the right end of the *cut stringer*, and  $H + x'$  the horizontal distance of  $m'$  from the vertical through the right support of the truss. Then in Fig. 1

$$m'n' : h :: x' : d, \quad \text{or} \quad m'n' = \frac{h}{d} x' = MN(H + x') \frac{1}{l}; \quad (20)$$

but

$$MN : s :: h : s + b, \quad \text{or} \quad MN = \frac{s}{s + b} h; \quad . \quad . \quad . \quad (21)$$

hence

$$m'n' = \frac{H+x'}{l} \cdot \frac{s}{s+b} h = \frac{h}{d} x', \quad . \quad . \quad . \quad (22)$$

and

$$(H+x') \frac{s}{l} = \frac{s+b}{d} x'; \quad . \quad . \quad . \quad (23)$$

this becomes

$$(H+x') \tan \theta_3 = x' \tan \theta_2. \quad . \quad . \quad . \quad (24)$$

The ordinate above the point  $G$  in the influence diagram satisfies this equality, and therefore  $G$  and  $m'$  are in the same vertical line.

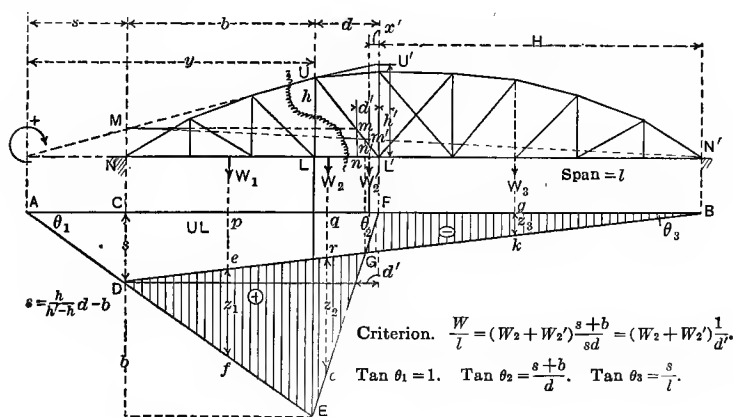


FIG. 2.

**Vertical of Pratt Truss with Inclined Top Chord.**—The truss diagram and the influence diagram are shown in Fig. 2.



All of the demonstrations given for Fig. 1 apply to Fig. 2. For all loads upon the left of the vertical through  $G$  the vertical is in tension and for those upon the right of  $G$  it is in compression.

**Web Member of Warren Truss with Inclined Top Chord.**  
—The web member  $U'L$ , Fig. 3 has been selected. A comparison with Fig. 1 shows that the influence diagram

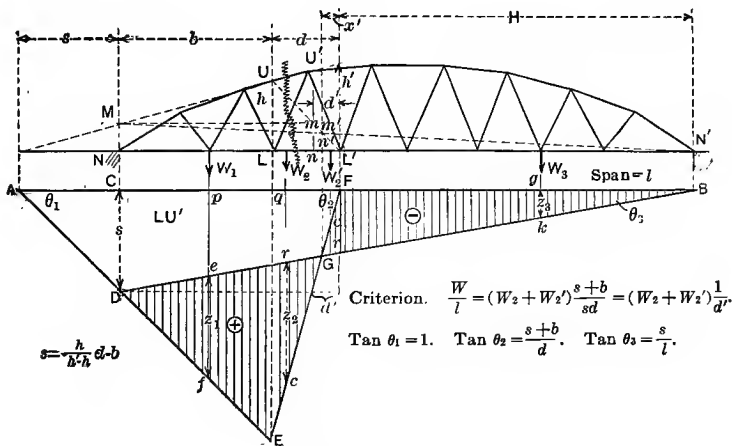


FIG. 3.

is constructed in exactly the manner followed in Fig. 1, and that all of the demonstrations of Fig. 1 apply equally well to Fig. 3. The locations of points  $m$  and  $m'$  are clearly shown in the figure where the verticals  $h$  and  $h'$  and the diagonal  $UL'$  are not members of the truss.

**Web Members in Simple Trusses Having Parallel Chords.**  
—The case shown in Fig. 4, presents an apparent exception to the general rule for drawing the influence line  $DEFB$ . The center of moments for any web member of a truss having parallel chords is at infinity. Taking  $N$ , the left

support of the truss, as a reference point  $s = \infty$ . For a load on the left of the vertical through  $E$ , the moment is

$$M_s = -W_1 \frac{l-a_1}{l} s + W_1(s+a_1) = -W_1 \frac{l-a_1}{l} \infty + W_1(\infty + a_1). \quad (25)$$

Dividing both members of equation (25) by  $+\infty$ .

$$\frac{M_s}{\infty} = -W_1 \frac{l-a_1}{l} + W_1 \left(1 - \frac{a_1}{\infty}\right) = -W_1 \frac{l-a_1}{l} + W_1. \quad (26)$$

But,  $-W_1 \frac{l-a_1}{l} + W_1$  is the expression for vertical shear on the right of  $W_1$ , and, consequently, practically at the load  $W_1$ .

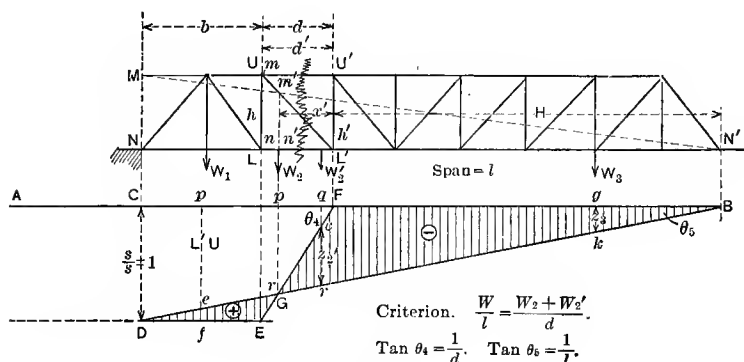


FIG. 4.

If  $CD$  is laid off equal to  $s \div \infty = 1$ , the ordinates of the influence diagram represent vertical shears instead of moments.  $DE$  drawn through  $A$ , which is an infinite

distance from  $N$ , will be sensibly parallel to  $ACB$ . It appears that the vertical shear influence diagram is constructed in precisely the manner outlined for the moment influence diagram when  $CD$  is made equal to unity.

For a load on the left of the vertical through  $E$ , the vertical shear between  $E$  and  $F$  is

$$-S = +W_1 \frac{l-a_1}{l} - W_1 = +W_1(l-a_1)\frac{1}{l} - W_1(1); \quad (27)$$

or

$$-S = +W_1(l-a_1) \tan \theta_5 - W_1(1) = W_1(+pe - pf);$$

therefore

$$+S = W_1(+ef). \quad \dots \quad (28)$$

In a similar manner it is shown that the ordinates directly below  $W_2$ ,  $W_2'$  and  $W_3$ , represent the vertical shears produced by unit loads at these points.

A negative ordinate in the influence diagram indicates that the resultant shear acts upward; therefore the vertical component of the stress in the web member, for which the influence diagram is drawn, acts downward. In Fig. 4, the member  $U'L'$  is in compression for loads on the left of  $G$ . The vertical  $UL$  has the same influence diagram but it is in tension for the same loads.

The criterion for maximum shear is determined in the manner given above for maximum moment. Without writing all of the equations and referring to equation (13) and Fig. 4,

$$\begin{aligned} \frac{\delta S}{\delta x} &= +W_2(-\tan \theta_5 + \tan \theta_4) - W_2'(-\tan \theta_4 + \tan \theta_5) \\ &\quad - W_3 \tan \theta_2 = 0. \quad \dots \quad (29) \end{aligned}$$



this becomes

$$\frac{W_1 + W_2 + W_3}{l} = \frac{W_1}{s} \quad \dots \quad (34)$$

An equivalent criterion is

$$\frac{W_2 + W_3}{l-s} = \frac{W_1}{s} = \frac{W_2 + W_3}{AB} = \frac{W_1}{AC} \quad \dots \quad (35)$$

This criterion holds good for any influence diagram which is triangular in shape.

**Top Chord of Curved-chord Simple Truss.**—The construction of the influence diagram follows the same general rule

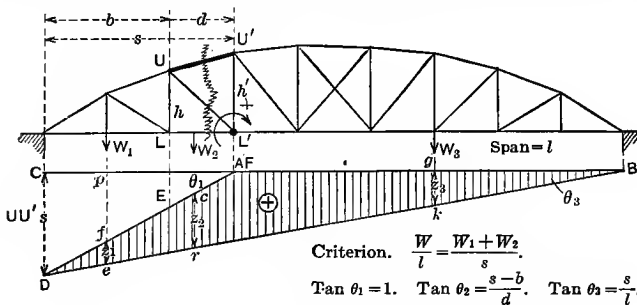


FIG. 6.

as in the previous case. The points  $A$  and  $F$ , Fig. 6 coincide, while  $E$  is on the right line connecting  $D$  and  $A$  since the line  $EF$  coincides with this line.

For wheel loads the criterion is

$$\frac{W_1 + W_2}{s} = \frac{W_3}{l-s} = \frac{W}{l}, \quad \dots \quad (36)$$

where  $W$  = the total load on the span.

**Bottom Chord of Curved-chord Warren Truss.**—If both sets of web members are inclined as shown in Fig. 7, the influence diagram remains unchanged in its construction, but the line  $EF$  does not coincide with the line  $DA$  as in the previous case.

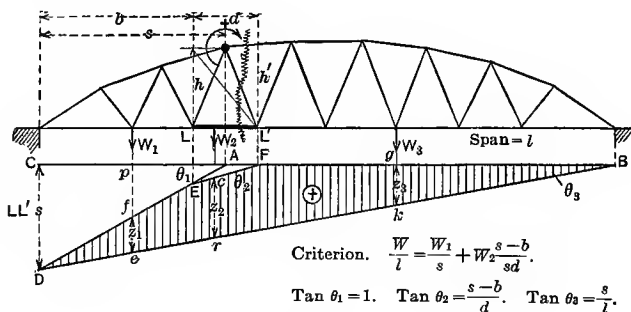


FIG. 7.

The criterion for the maximum moment produced by wheel loads is found as follows:

$$\frac{\delta M_s}{\delta x} = W_1(-\tan \theta_1 + \tan \theta_3) + W_2(-\tan \theta_2 + \tan \theta_3) + W_3 \tan \theta_3 = 0. \quad (37)$$

$$= (W_1 + W_2 + W_3) \tan \theta_3 - W_1 \tan \theta_1 - W_2 \tan \theta_2 = 0, \quad (38)$$

Substituting the values of the tangents, equation (38) becomes

$$(W_1 + W_2 + W_3) \frac{s}{l} - W_1 - W_2 \frac{s-b}{d} = 0. \quad (39)$$

Hence

$$\frac{W}{l} = \frac{W_1}{s} + W_2 \frac{s-b}{sd}. \quad \dots \dots \dots (40)$$

If  $s-b = \frac{1}{2}d$ , then

$$\frac{W}{l} = \frac{W_1 + \frac{1}{2}W_2}{s}. \quad \dots \dots \dots (41)$$

**Trusses with Sub-divided Panels.**—The usual type of truss with sub-divided panels has one set of web members vertical. The trusses here considered will have one set of web members vertical and the chords not parallel. The only difficulty in constructing the moment influence diagram is the determination of the proper length of the *cut stringer*. This once determined the construction of the diagram follows the general rule.

**Lower Segment of Diagonal in Sub-strut Truss.**—Let  $VL''$ , Fig. 8, be the lower segment considered. This is a portion of the diagonal  $UL''$  of the main truss and also forms a chord member of the auxiliary truss  $LVL''$ .

Considering the member  $VL''$  as a part of the diagonal of the main truss, the influence diagram  $DD'FBD$  is constructed in the usual manner. The auxiliary truss  $LVL''$  may be considered as a simple truss supported at  $L$  and  $L''$ . The center of moments for  $VL''$  may be taken anywhere in  $LL''$  or  $LL''$  produced and in order that the lever arm of  $VL''$  shall be the same as that for  $UL''$  the center of moments will be taken at the intersection of  $UU''$  and  $LL''$  produced, the center of moments for  $UL''$ . The influence diagram, constructed according to the general rule, is  $D'EB'$ . Combining the two diagrams just constructed, the final influence diagram for  $VL''$  is  $DEFBD$ . This diagram is the same as if constructed

with the horizontal projection of  $VL''$  as the length of the *cut stringer*. The values of  $x'$  and  $d'$  can now be found in the usual manner from the truss diagram.

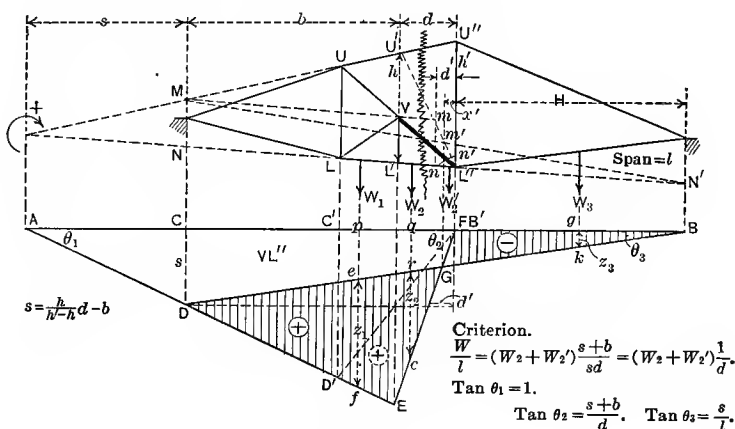


FIG. 8.

The criterion for the position of wheel loads producing maximum moment is found in the manner previously explained. Referring to equation (13) and Fig. 8.

$$\frac{\delta M_s}{\delta x} = W_2(-\tan \theta_3 + \tan \theta_2) - W_2'(\tan \theta_3 - \tan \theta_2) - W_3 \tan \theta_3 = 0, \quad (42)$$

or

$$(W_2 + W_2' + W_3) \tan \theta_3 = (W_2 + W_2') \tan \theta_2. \quad (43)$$

Substituting the values of the tangents

$$W \frac{s}{l} = (W_2 + W_2') \frac{s+b}{d}, \quad (44)$$



and

$$\frac{W}{l} = (W_2 + W_2') \frac{s+b}{sd} = \frac{(W_2 + W_2')}{d'}, \quad \dots \quad (45)$$

which is the required criterion.

In case the chords are parallel  $s$  becomes  $\infty$  and the criterion is

$$\frac{W}{l} = \frac{W_2 + W_2'}{d}. \quad \dots \quad (46)$$

**Upper Segment of Diagonal in Sub-strut Truss.**—Referring to Fig. 9, it is clear that the diagonal  $UV$  has the

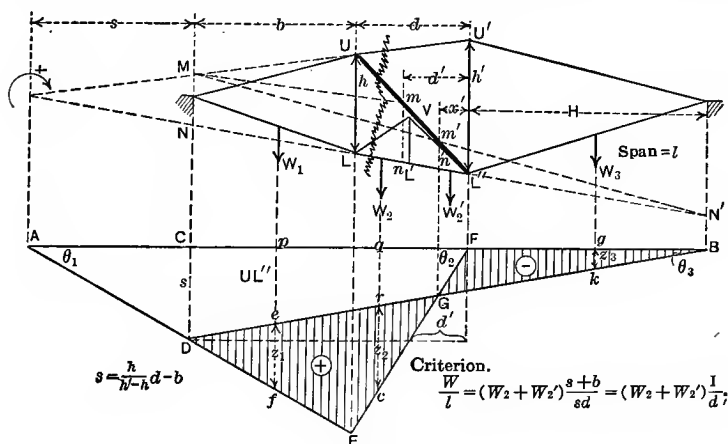


FIG. 9.

stress of  $UL'$ , the diagonal of the main truss, as the auxiliary truss  $LVL'$  simply serves the purpose of a *trussed stringer* extending from  $L$  to  $L'$ . The influence diagram is constructed according to the general rule taking the length of the *cut stringer* as the horizontal projection

of  $LL''$ . The graphical determination of  $d'$  and  $x'$  is evident from the truss diagram.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = (W_2 + W_2') \frac{s+b}{sd} = (W_2 + W_2') \frac{1}{d'}. \quad (47)$$

If the chords are parallel the criterion becomes

$$\frac{W}{l} = \frac{W_2 + W_2'}{d}. \quad (48)$$

**Vertical of Sub-strut Truss.**—As indicated in Fig. 10, the vertical of a sub-strut truss is a member of the main truss.

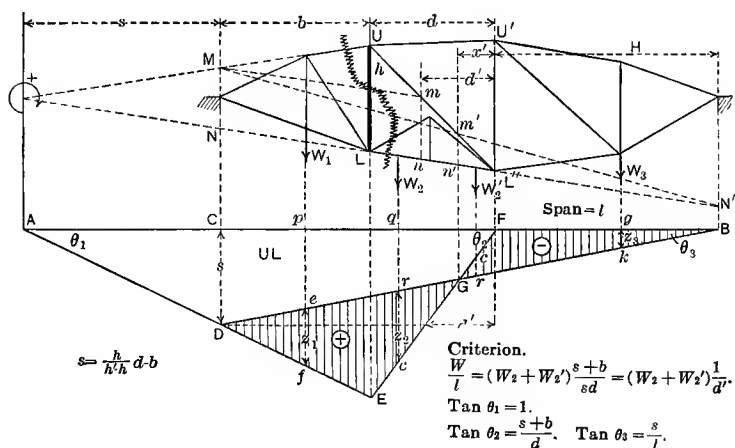


FIG. 10.

The auxiliary truss acts simply as a *trussed stringer*. The construction of the influence diagram follows the general rule using the horizontal projection of  $LL''$  as the length

of the *cut stringer*. The graphical determinations of  $d'$  and  $x'$  are clearly shown in Fig. 10.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = (W_2 + W_2') \frac{s+b}{sd} = (W_2 + W_2') \frac{1}{d'}. \quad (49)$$

**Upper Segment of Diagonal in Sub-hanger Truss.**—The member  $UV$  in Fig. 11, is a part of the diagonal  $UL''$  of

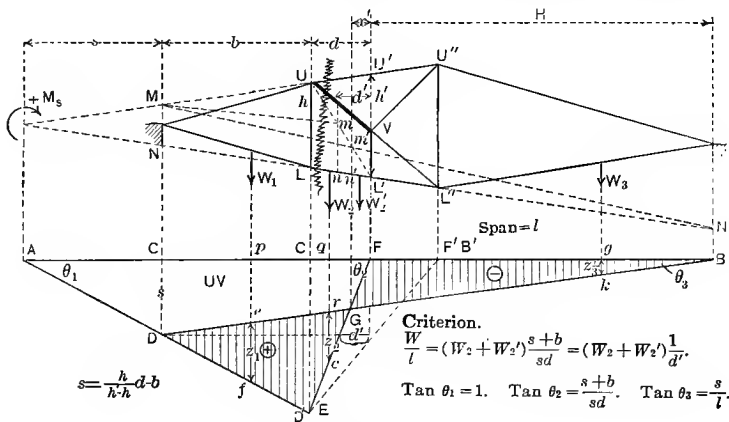


FIG. 11.

the main truss and also a chord member of the auxiliary truss  $UVU''$ . The influence diagram for  $UL'$  is  $DEF'BD$  and that for the chord  $UV$  is  $D'FB'$ . The combination of these two diagrams gives the influence diagram  $DEFBD$ . This diagram is constructed according to the general rule when the horizontal projection of  $UV$  is taken as the length of the *cut stringer*. The graphical determination of  $x'$  and  $d'$  requires no explanation as the constructions are evident in Fig. 11.



**Vertical of Sub-hanger Truss.**—In Fig. 13, the *cut stringer* for the vertical  $UL$  is the horizontal projection of  $LL'$ , since no part of the load on  $L'L''$  is supported at  $L$ . The construction of the influence diagram follows the general rule. In determining  $x'$  and  $d'$  from the truss diagram,  $h'$  and the diagonal  $UL'$  form no part of the truss proper.

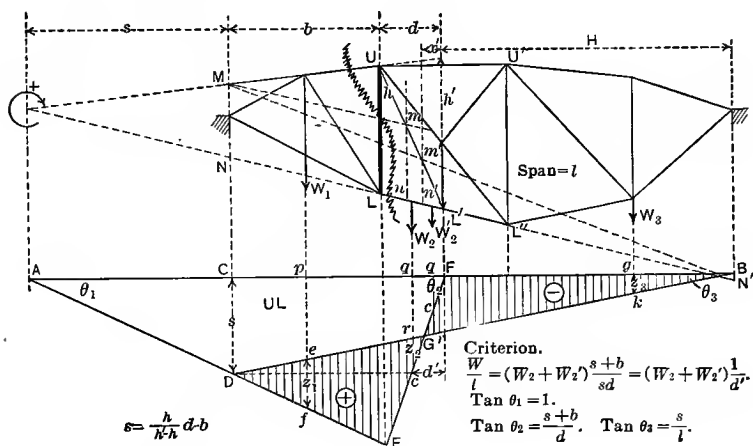


FIG. 13.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = \frac{W_2 + W_2'}{d'} \dots \dots \dots (52)$$

**Bottom Chord of Sub-strut Truss.**—The bottom chord  $L_4L_5$  in Fig. 14 is a part of the chord of the main truss and also a part of the chord of the auxiliary truss  $L_3VL_5$ . Considering only the chord  $L_3L_5$  of the main truss the influence diagram is  $DABD$ . Now considering the chord  $L_4L_5$  of the auxiliary truss  $L_3VL_5$  and taking the center of



If the line  $DA$  is prolonged until it cuts the vertical through  $K$  the ordinate cut-off above  $K$  equals  $AK$  and hence it cuts the vertical at  $E$ , and  $EK$  in the small diagram equals  $EK$  of the large diagram. This shows, if the horizontal projection of  $VL_5$  is taken as the length of the *cut stringer* and an influence diagram constructed according to the general rule, that this is the true influence diagram for  $VL_5$ .

The criterion for wheel loads producing maximum moment is found as follows:

$$\frac{\delta M_s}{\delta x} = W_1(-\tan \theta_1 + \tan \theta_3) + W_2(-\tan \theta_1 + \tan \theta_3) + W_2'(\tan \theta_2 + \tan \theta_3) + W_3 \tan \theta_3 = 0; \quad (53)$$

then

$$W \tan \theta_3 = (W_1 + W_2) \tan \theta_1 - W_2' \tan \theta_2. \quad (54)$$

Substituting the values of the tangents and dividing through by  $s$

$$\frac{W}{l} = (W_1 + W_2) \frac{1}{s} - W_2' \frac{b-s}{sd}. \quad (55)$$

If  $b-s=d$ , then

$$\frac{W}{l} = \frac{W_1 + W_2 - W_2'}{s}. \quad (56)$$

**Top Chord of Sub-strut Truss.**—In Fig. 15 the top chord  $UU'$  has no double duty to perform as it is simply a chord member of the main truss. The influence diagram is drawn according to the general rule using the horizontal projection of the chord  $UU'$  as the length of the *cut stringer*.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = \frac{W_1 + W_2}{s}. \quad \dots \quad (57)$$

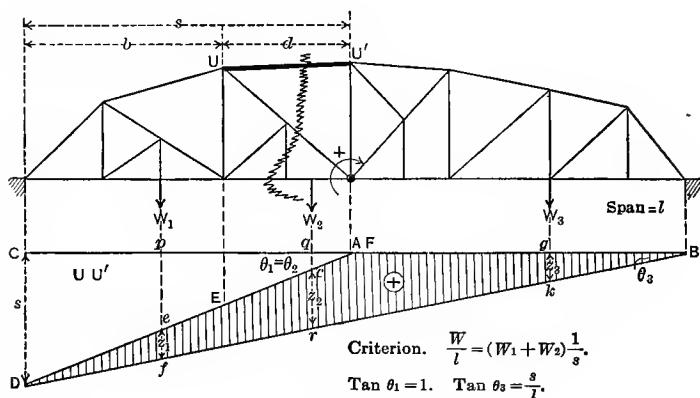


FIG. 15.

**Top Chord of Sub-hanger Truss.**—Referring to the explanations given for Fig. 14, the horizontal projection of  $UV$ , Fig. 16, is taken as the length of the *cut stringer* and the influence diagram constructed according to the general rule.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = \frac{W_1}{s} + \frac{W_2(s-b)}{sd}. \quad \dots \quad (58)$$

If  $s-b=2d$ , then

$$\frac{W}{l} = \frac{W_1 + 2W_2}{s}. \quad \dots \quad (59)$$



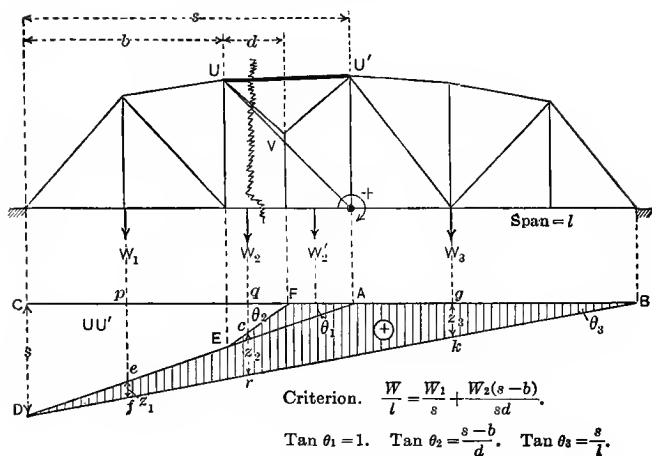


FIG. 16.

**Bottom Chord of Sub-hanger Truss.**—This case follows the general rule for simple trusses. The influence diagram is shown in Fig. 17.

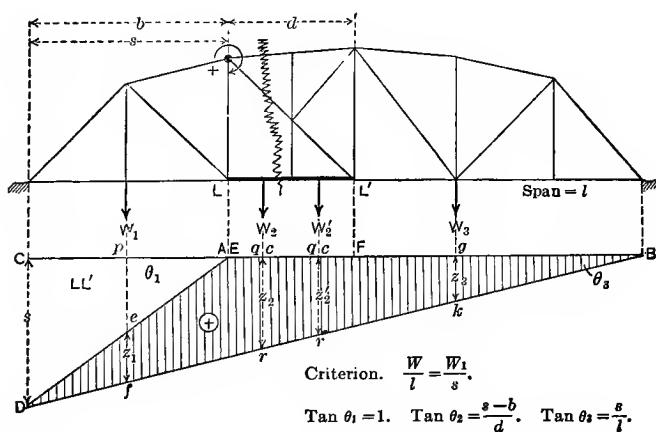


FIG. 17.

The criterion for wheel loads producing maximum moment is

$$\frac{W}{l} = \frac{W_1}{s} \cdot \dots \dots \dots (60)$$

**The Length of the Cut Stringer** for trusses with sub-struts or sub-hangers of the type considered above, can be readily determined by the following rules.

(a) *For diagonal members:* whenever the section cuts the segment which is a part of the main diagonal and also a part of the auxiliary truss, the length of the *cut stringer* is the horizontal projection of the segment cut.

(b) *For diagonal members:* whenever the section cuts the segment which is a part of the diagonal of the main truss and forms no part of the auxiliary truss, the length of the *cut stringer* is the horizontal projection of the diagonal of the main truss.

(c) *For chord members:* whenever the section cuts the chord which forms a part of the main truss chord and also a part of the auxiliary truss, the length of the *cut stringer* for this chord is the horizontal projection of the diagonal segment cut by the section. Otherwise the length of the *cut stringer* is the horizontal projection of the chord, of the main truss, which is cut.

(d) *For vertical members of the main truss:* whenever the section cuts any portion of the auxiliary truss the length of the *cut stringer* is the horizontal projection of the diagonal of the main truss. In case the section does not cut the auxiliary truss the length of the *cut stringer* is the horizontal projection of the segment of the diagonal adjacent to the vertical.

## SPECIAL CASE

**Diagonal of Simple Truss, Having Center of Moments between the Supports.**—In Fig. 18 make a section cutting two chords and the diagonal  $UL'$ . The intersection of the two chord members is between the supports, a condition which has not obtained in any of the previous examples. The influence diagram for moments is constructed according

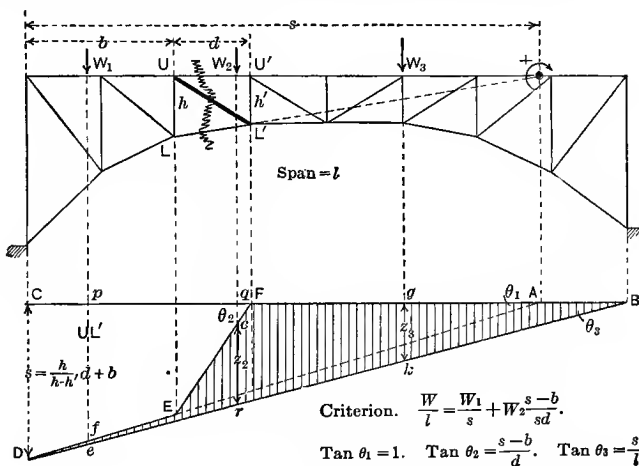


FIG. 18.

to the general rule and is shown by the shaded area in Fig. 18. This diagram shows that each and every load placed upon the span produces the same kind of stress in the diagonal  $UL'$ .

The criterion for the position of wheel loads which produce the maximum moment is found as follows:

$$\frac{\delta M_s}{\delta x} = W_1(-\tan \theta_1 + \tan \theta_3) + W_2(-\tan \theta_2 + \tan \theta_3) + W_3 \tan \theta_3 = 0, \dots \dots (61)$$

or

$$W \tan \theta_3 = W_1 \tan \theta_1 + W_2 \tan \theta_2. \quad . \quad . \quad (62)$$

Substituting the values of the tangents

$$\frac{W}{l} = \frac{W_1}{s} + W_2 \frac{s-b}{sd}, \quad . \quad . \quad . \quad (63)$$

where  $W$  is the total load on the span.

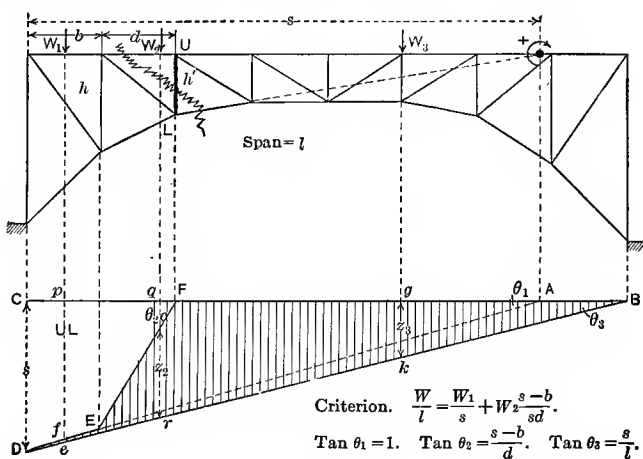


FIG. 19.

**Vertical of Simple Truss Having Center of Moments between the Supports.**—The vertical member  $UL$ , Fig. 19, has its center of moments between the supports. The moment influence diagram is constructed according to the general rule and is the shaded area in Fig. 19. This diagram

is similar to that in Fig. 18 and therefore the criterion locating wheel loads which produce the maximum moment is

$$\frac{W}{l} = \frac{W_1}{s} + W_2 \frac{s-b}{sd}. \quad . \quad . \quad . \quad . \quad (64)$$

## CHAPTER II

### DOUBLE INTERSECTION TRUSSES

**Double Intersection Trusses** are made up of two or more simple trusses and the influence diagram for any member is found by first drawing the influence diagram for each simple truss and then connecting these diagrams so as to form one diagram. This is shown in the following examples.

**Top Chord of Whipple Truss.**—The Whipple truss shown in Fig. 20 is made up of two simple trusses as indicated by the full and dotted lines of the truss diagram.

The chord  $U_3U_4$  is a part of the top chord of both trusses. Considering it as a top chord member of the truss shown by the full lines, the center of moments is at  $L_4$  and the length of the *cut stringer* is  $L_4L_6$ . The influence diagram  $DAFBD$  is constructed according to the general rule. When the member  $U_3U_4$  is considered as a part of the top chord of the dotted truss, the center of moments is at  $L_5$ , the length of the *cut stringer* is  $L_5L_7$  and the influence diagram is  $DA'F'B'D'$ . This diagram is constructed upon the line  $DB$  of the first diagram by making  $D'C'$  equal  $s'$ . Now a load at  $L_2$  does not affect the members of the dotted truss and hence the ordinate  $ef$  in the influence diagram for the truss shown by full lines is the correct moment for a unit load at  $L_2$ . A load at  $L_3$  by similar reasoning has for its true ordinate  $e'f'$  in the influence diagram for the dotted truss. For a

load between  $L_2$  and  $L_3$  the influence line is a straight line connecting  $e$  and  $e'$ . In a like manner the other panel points are considered and the final influence diagram, shown by the shaded area, obtained. The loads at  $L_1$  and  $L_{11}$  are assumed to be equally divided between the two trusses and hence the influence line passes midway between the two influence diagrams for these points.

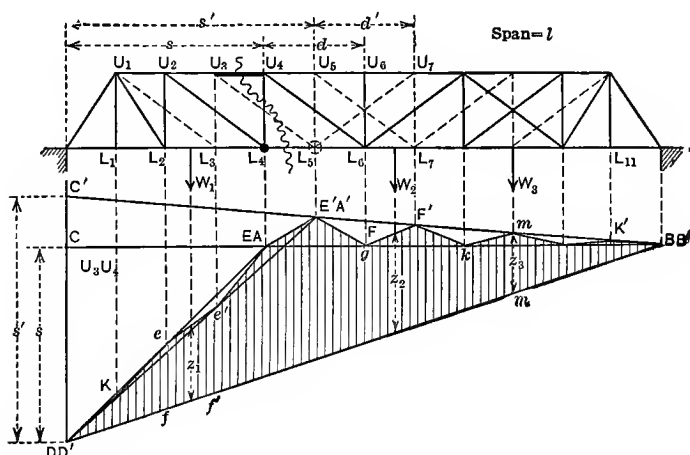


FIG. 20.

The position of wheel loads producing maximum moment is best found by trial. A criterion can be deduced but it is too complicated for practical use.

**Vertical of Whipple Truss.**—The vertical  $U_4L_4$  is a member of the truss shown by the full lines, Fig. 21. The influence diagram for vertical shear in the panel cut is  $DEFBD$ . For loads at panel points  $L_2$ ,  $L_4$ ,  $L_6$ , etc., the ordinates of this influence diagram are correct for unit loads. The loads at  $L_3$ ,  $L_5$ ,  $L_7$ , etc., are supported entirely by the truss shown by dotted lines and hence do not contribute any shear in the panel being considered, of the

truss shown by the full lines. Therefore, the ordinates in the influence diagram directly below these points are zero. Connecting these points with the ends of the ordinates which are correct, as shown in Fig. 21, the influence diagram shown by the shaded area is obtained. The loads  $L_1$  and  $L_{11}$  are assumed to be equally divided between the two trusses.

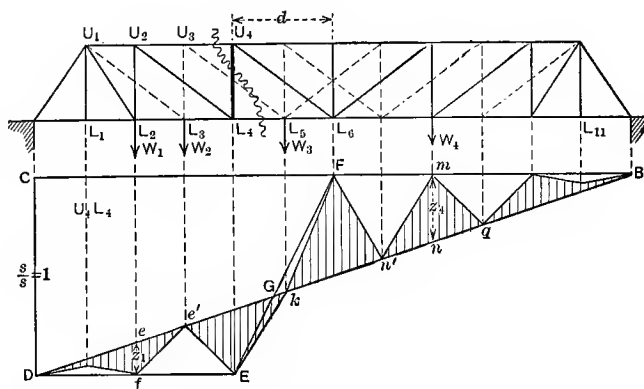


FIG. 21.

**Diagonal of Whipple Truss.**—The diagonal  $U_2L_4$ , Fig. 22 is a member of the truss shown by full lines and its influence diagram is constructed in a manner similar to that explained for the vertical  $U_4L_4$ . The influence diagram is shown by the shaded areas.

The position of wheel loads producing the maximum vertical shear is found by trial.

**Top Chord of Sub-divided Double Triangular Truss.**—The two principal trusses are shown in Fig. 23 by full and dotted lines. The top chord member  $U_6U_8$  forms a part of each truss. The influence diagram for  $U_6U_8$  as a member of the truss shown by full lines is  $DABD$  and that for the truss shown by dotted lines is  $D'A'B'$ . Connecting these



two diagrams in the manner explained for the Whipple truss the influence diagram shown by the shaded area is obtained.

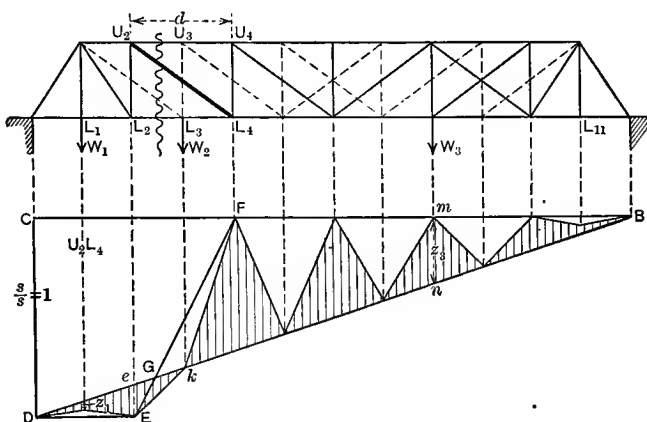


FIG. 22.

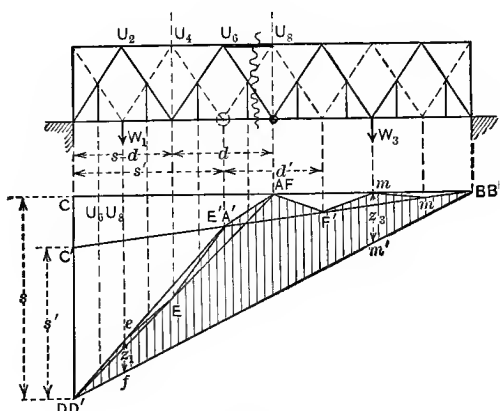


FIG. 23.

The position of wheel loads producing the maximum moment is found by trial.

**Bottom Chord of Sub-divided Double Triangular Truss.**—The bottom chord member  $L_4L_6$ , Fig. 24 is a part of the

two simple trusses and also a part of the auxiliary frame  $L_4M_3L_6$ . Neglecting the auxiliary truss  $L_4M_3L_6$ , the influence diagram is drawn in the manner outlined for a top chord member. This diagram is  $DED''B''Fn'$ , etc., and for a load of unity anywhere between  $L_4$  and  $L_6$  the moment is equal to the ordinate immediately below the load between the lines  $D''B''$  and  $DB$ , and the stress in  $L_4L_6$  equals this moment divided by the depth of the truss. The stress in  $L_4L_6$  as a part of the auxiliary truss  $L_4M_3L_6$  can

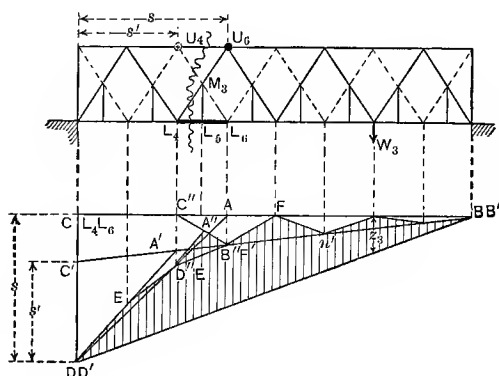


FIG. 24.

be found by drawing the influence diagram for  $L_4L_5$  and dividing the ordinate directly below the load by the length  $L_5M_3$ . If the scale of this diagram is properly taken the ordinates may be added directly to those of the large diagram.

Following the general rule for constructing influence diagrams, with  $D''C''$ , Fig. 24, equal to  $s'' = L_4L_5$  multiplied by  $L_4U_4 \div L_5M_3$ , the diagram  $D''A''B''$  is obtained. The ordinates are increased in the same ratio as the ratio of the lever arms of  $L_4L_6$ . The shaded area is the influence diagram for  $L_4L_6$ . This is simply the proper combination

of three diagrams for simple trusses. For the truss shown  $C''$  falls in the line  $CB$ . This method of constructing the influence diagram requires no preliminary calculations.

As in the previous case the position of wheel loads producing the maximum moment is best found by trial.

**Lower Segment of Diagonal in Sub-divided Double Triangular Truss.**—Selecting the member  $L_4M_3$ , Fig. 25, it is at once seen that it forms a part of the diagonal of the truss

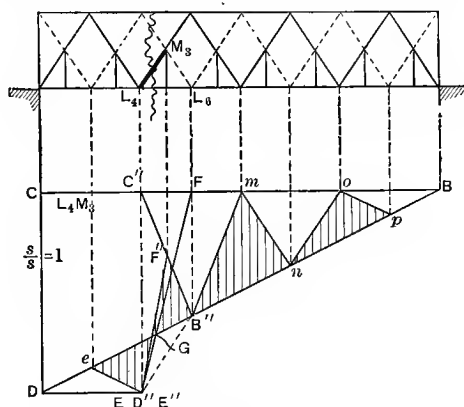


FIG. 25.

shown by full lines and also a part of the auxiliary truss  $L_4M_3L_6$ . The influence diagram for vertical shear, neglecting the effect of the auxiliary truss, is  $DeD''B''mnopBD$ . The shear diagram for  $L_4M_3$  as a member of the auxiliary truss is  $D''F''B''D''$ . This is constructed according to the general rule using the line  $D''B''$  as the line  $DB$  in the usual diagram. The influence diagram for  $L_4M_3$  now becomes the shaded area in Fig. 25.

The position of wheel loads producing the maximum vertical shear is found by trial.

**Chords of the "K" Truss.**—The truss shown in Fig. 26 is called the "K" truss since the web members form

a series of the letter K. Making a section cutting  $U_2U_3$ ,  $U_3M_2$ ,  $M_2L_3$  and  $L_2L_3$ , it at once appears that the upper and lower chord members in a panel have equal horizontal components since the centers of moments are in the same vertical line.

The construction of the influence diagram for moments

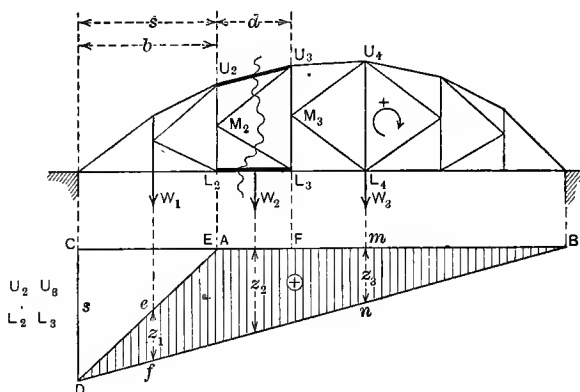


FIG. 26.

follows the general rule. The criterion for wheel loads which provide the maximum moment is

$$\frac{W}{l} = \frac{W_1}{s}, \quad \dots \dots \dots (65)$$

where  $W$  is the total load on the span and  $W_1$  the total load between the left support of the truss and the center of moments of the chords considered.

**Diagonal Web Members of the "K" Truss.**—The usual method of sections cannot be employed as any section made through the truss cuts at least four members. From the arrangement of the diagonals it is clear that the pair in one panel must have horizontal components equal in

magnitude but opposite in character. The magnitude of this component is equal to the difference between the horizontal components of the stresses in the chords in the panel containing the diagonals being considered and the adjacent panel opposite the point of intersection of the diagonals. In Fig. 27 the horizontal components of the diagonals  $U_3M_2$  and  $M_2L_3$  is the difference between the horizontal components of the chords in this panel and the panel immediately upon the right.

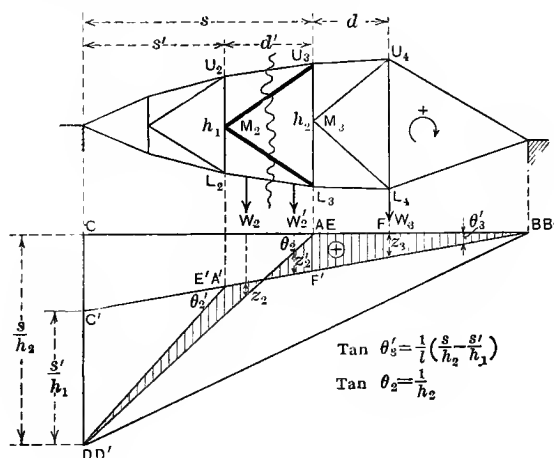


FIG. 27.

The influence diagram for the horizontal component of  $U_3U_4$  and  $L_3L_4$  can be constructed according to the general rule by laying off  $CD$  equal to  $s \div h_2$ . On  $DB$  as a base construct a similar diagram for the chords  $U_2U_3$  and  $L_2L_3$ , the difference between these diagrams as shown by the shaded areas in Fig. 27 being the influence diagram for the horizontal components of the diagonals  $U_3M_2$  and  $M_2L_3$ . The stress in any diagonal equals its horizontal component multiplied by the secant of the angle it makes with the horizontal.

The criterion for the position of wheel loads which produce maximum stresses is found as follows:

$$-W_2(-\tan \theta_3' + \tan \theta_2) + W_2'(\tan \theta_3' - \tan \theta_2) + W_3 \tan \theta_3' = 0, \quad (66)$$

or

$$W(\tan \theta_3') = (W_2 + W_2') \tan \theta_2. \quad \dots \quad (67)$$

Substituting the values of the tangents,

$$\frac{W}{l} = (W_2 + W_2') \frac{h_2}{sh_2 - s'h_1}. \quad \dots \quad (68)$$

In case the chords are parallel, then  $h_1 = h_2$  and  $s - s' = d'$  and the criterion becomes the same as developed for Fig. 4.

**Upper Segment of Vertical in the "K" Truss.**—In Fig. 28 a section cutting the upper segment of the vertical  $U_3L_3$

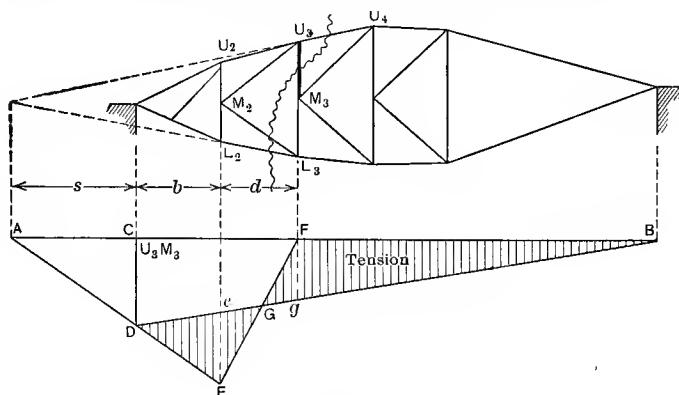


FIG. 28.

also cuts the members  $U_3U_4$ ,  $M_2L_3$ , and  $L_2L_3$ . Taking the center of moments at the intersection of the chord members  $U_3U_4$  and  $L_2L_3$ , the moment influence diagram

is constructed according to the general rule. In this case the stress in  $U_3M_3$  is not equal to the ordinates of the diagram divided by the lever arm  $s+b+d$ , since a portion of each ordinate corresponds to the moment of the stress in the diagonal  $M_2L_3$ . The simplest way to utilize the influence diagram is to first determine the stress in  $U_3M_3$  for a unit load at  $L_3$ . (This can be very quickly done graphically.) Then below  $F$  in the influence diagram lay

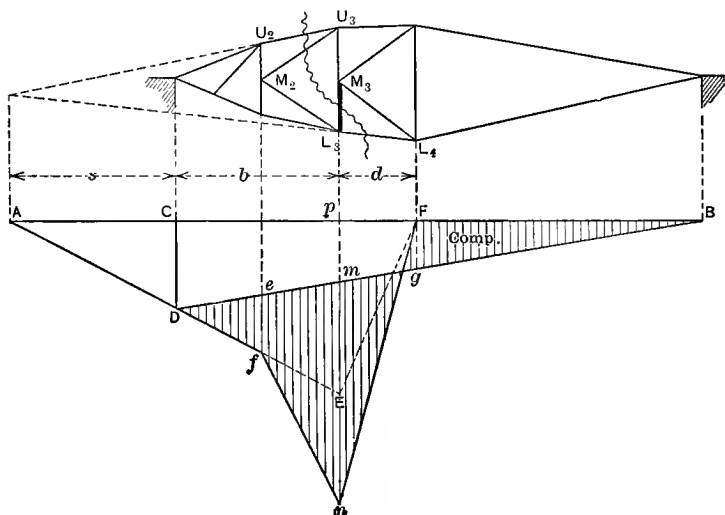


FIG. 29.

off to any convenient scale the distance  $Fg$  equal to this stress. Draw a straight line through  $B$  and  $g$  and extend it until the point  $D$  is located. Complete the diagram according to the general rule. The ordinates in this diagram correspond to the actual stresses in the piece  $U_3M_3$  produced by a unit load moving across the span.

**Lower Segment of Vertical in the "K" Truss.**—As in the case of the upper segment it is impossible to make a section which does not cut at least four members of the truss. Practically the same method is employed as outlined for

the upper segment. Graphically determine the stress in  $M_3L_3$  produced by a unit load at  $L_4$  and lay off this stress below  $F$  as  $Fg$ . Locate  $D$  by drawing a straight line through  $B$  and  $g$  and then complete the influence diagram according to the general rule. This gives the diagram  $DEFBD$ . A unit load at  $L_3$  produces a stress in  $M_3L_3$  due to its position in the principal truss and also a local stress considering  $M_3L_3$  as a piece which simply transfers a portion of the load at  $L_3$  to the main truss. While the stress in  $M_3L_3$  produced by a unit load at  $L_3$  is readily computed yet it is usually more satisfactory to find this stress graphically by means of an ordinary stress diagram. After this stress is found, lay off  $mn$  equal to it and connect  $f$  and  $n$  and  $F$  and  $n$ . The shaded area shown is the stress influence diagram for the member  $M_3L_3$ .



## CHAPTER III

### CONTINUOUS TRUSSES

**The Moment Influence Diagrams** for various forms of simple trusses have been explained in detail and found to follow a single general rule in their construction. After the distance of the center of moments from the left support of the span is determined the diagram is constructed without further calculations and the ordinates are the moments for unit loads, on the truss, directly above.

For trusses which are continuous, or partially continuous, the moment influence diagrams are founded upon the influence diagram for simple trusses. The diagram for simple trusses will be called the *base diagram* for convenience.

**General Moment Formula.**—Considering any span of a continuous girder, let

$M_s$  = the moment about a center of moments distant  $s$  from the left end of the span.

$M_L$  = the bending moment at the left end of the span.

$M_R$  = the bending moment at the right end of the span.

$S_L$  = the vertical shear at the left end of the span.

$W$  = any concentrated vertical load in the span.

$a$  = the distance of  $W$  from the left end of the span.

$R_1$  = the left reaction produced by  $W$  considering the span as a simple beam on two supports.

$l$  = the length of the span.

$m_s$  = the moment about a center of moments distant  $s$  from the left support of the truss, considering the truss as a simple girder on two supports.

$s$  = the distance of the center of moments from the left end of the span. Positive when measured to the right.

Then

$$M_s = M_L + S_L s - W(s - a), \quad . \quad . \quad . \quad . \quad (a)$$

but

$$S_L = \frac{M_R - M_L}{l} + R_1; \quad . \quad . \quad . \quad . \quad (b)$$

therefore

$$M_s = M_L + \frac{M_R - M_L}{l} s + R_1 s - W(s - a). \quad . \quad (c)$$

Now,  $R_1 s - W(s - a) = m_s$ ,

hence

$$M_s = M_L \frac{l-s}{s} + M_R \frac{s}{l} + m_s. \quad . \quad . \quad . \quad . \quad (d)$$

This expression shows that the influence diagram for  $M_s$  may be considered as being composed of two separate diagrams combined algebraically. One of the diagrams is that for the common moment  $m_s$ , or the *base diagram*. It will be shown in the problems which follow that the influence diagram for  $M_s$  can be easily constructed upon the base diagram and with a small amount of calculation.

**Cantilever Truss.**—Truss bridges which are called cantilever bridges are composed of anchor spans, cantilever spans and suspended spans. The simplest form of this combination is shown in Fig. 30.

**Top Chord of Anchor Span.**—Assume any chord as  $U_2U_3$ , Fig. 30, with its center of moments at  $L_2$ . For loads in this span the influence diagram is the *base diagram* representing the moments  $m_s$  in equation (d), since the moments  $M_L$  and  $M_R$  are zero.

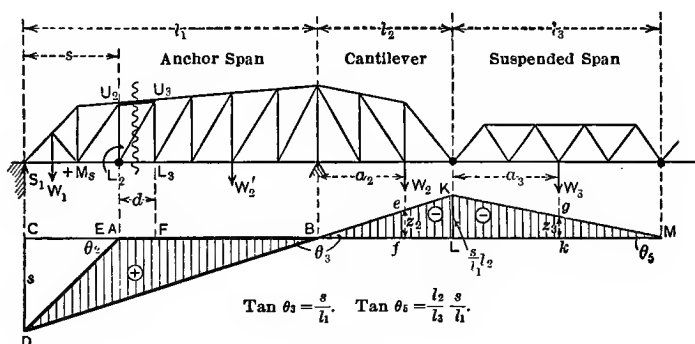


FIG. 30.

The criterion for wheel loads in this span which produce the maximum moment is

$$\frac{W_1}{s} = \frac{W_2'}{l-s} \quad \dots \quad (69)$$

For loads in the cantilever span  $M_L=0$ ,  $M_R=-W_2a_2$ , and from equation (d),

$$M_s = -W_2a_2 \frac{s}{l_1} = -W_2a_2 \tan \theta_3 = W_2(-ef) \quad \dots \quad (70)$$

This shows that the lines  $DB$  and  $CB$  of the *base diagram* are extended until they cut the vertical through the right end of the cantilever. The influence diagram is shown by the shaded area  $BKL$ .

For loads in the suspended span,

$$M_L = 0, \quad M_R = -W_3 \frac{l_3 - a_3}{l_3} l_2, \quad m_s = 0,$$

and hence

$$M_s = -W_3(l_3 - a_3) \frac{s}{l_1} \cdot \frac{l_2}{l_3}. \quad . \quad . \quad . \quad (71)$$

This is the equation for the straight line  $KM$  when  $\tan \theta_5 = \frac{s}{l_1} \frac{l_2}{l_3} = \frac{KL}{l_3}$ . The shaded area in Fig. 30 is the complete moment influence diagram for the chord  $U_2 U_3$ .

The criterion for wheel loads which produce the maximum *negative* moment is

$$\frac{W_2}{l_2} = \frac{W_3}{l_3}.$$

**Top Chord of Cantilever Span.**—The chord member,  $U_1 U_2$ , Fig. 31 will be considered. For loads in this span  $M_L = -W_2 a_2$ ,  $M_R = 0$  and hence, from equation (d),

$$M_s = -W_2 a_2 \frac{l_2 - s}{l_2} + m_s. \quad . \quad . \quad . \quad (72)$$

The *base diagram* is first constructed for the term  $m_s$  as shown by the heavy lined triangle in Fig. 31. Prolong the line  $DA$  to  $K$ ; then from the triangle  $DKB$ ,

$$b'c' : KB :: a_2 : l_2,$$

and

$$b'c' = \frac{a_2}{l_2} KB = a_2 \frac{l_2 - s}{l_2}.$$

But this expression for  $b'c'$  is the same as the coefficient of  $W_2$  in the expression for  $M_s$  and hence the triangle  $DKB$  is the influence diagram for  $W_2 a_2 \frac{l_2 - s}{l_2}$ . Since the ordinates of the *base diagram* are positive and the ordinates of this diagram are negative, the combination of the two

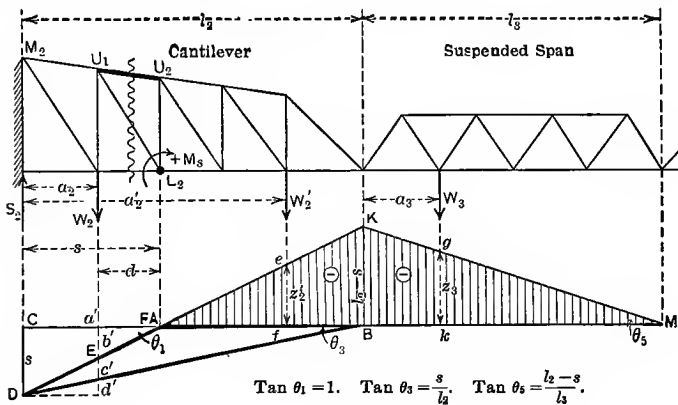


FIG. 31.

diagrams produces the shaded area  $AKB$  as the influence diagram for loads in the cantilever span.

For loads in the suspended span the influence diagram is the shaded area  $KBM$ .

The criterion for wheel loads which produce the maximum moment is

$$\frac{W_2'}{l_2 - s} = \frac{W_3}{l_3} \quad \dots \quad (73)$$

**Diagonal of Anchor Span.**—As shown in Fig. 32, the diagonal  $U_3L_2$ , has its center of moments at the intersection of the two cut chords  $U_2U_3$  and  $L_2L_3$ . For loads in this span the moment influence diagram is the base diagram as shown by heavy lined shaded figure in Fig. 32.

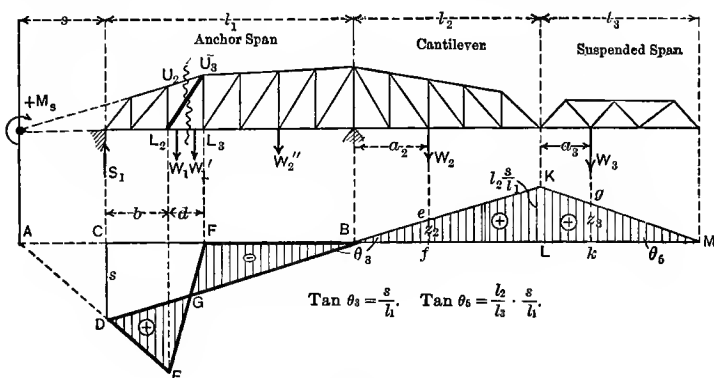


FIG. 32.

The criterion for wheel loads in this span which produce the maximum moment is

$$\frac{W}{l_1} = (W_1 + W_1') \frac{s+b}{sd} \quad . \quad . \quad . \quad (74)$$

For loads in the cantilever span,  $M_L = 0$ ,  $M_R = -W_2a_2$ ,  $m_s = 0$ , and

$$M_s = -W_2a_2 \left( \frac{-s}{l_1} \right) = W_2a_2 \frac{s}{l_1} \quad . \quad . \quad . \quad (75)$$

Since  $\frac{s}{l_1}$  is the tangent of the angle  $\theta_3$  the influence diagram for  $M_s$  is the shaded area  $BKL$ .

For loads in the suspended span the influence diagram is the shaded area  $KLM$ .

The criterion for wheel loads which produce the maximum *positive* moment is

$$\frac{W_2}{l_2} = \frac{W_3}{l_3}. \quad \dots \dots \dots (76)$$

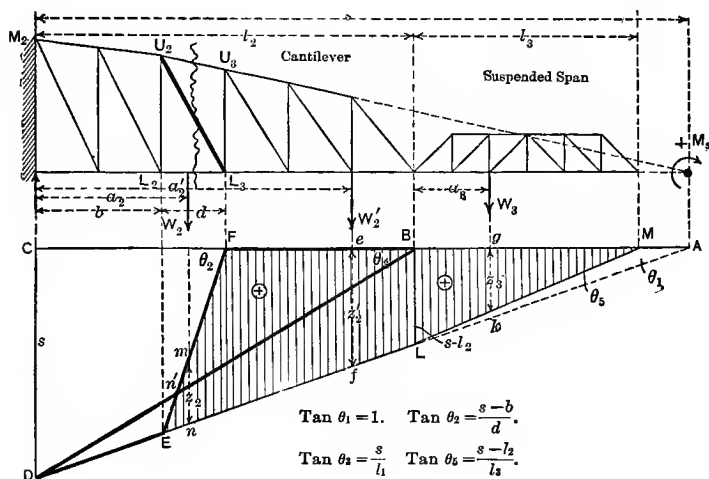


FIG. 33.

**Diagonal of Cantilever Span.**—Referring to Fig. 33, for loads in the cantilever span  $M_L = -W_2 a_2$ ,  $M_R = 0$ , and

$$M_s = -W_2 a_2 \frac{l_2 - s}{l_2} + m_s. \quad \dots \dots \dots (77)$$

The influence diagram for  $m_s$  is the *base diagram* shown by the heavy lines in Fig. 33. From the triangle  $DBL$ ,

$$n'n : BL :: a_2 : l_2,$$

and

$$n'n = \frac{a_2}{l_2} BL = \frac{a_2}{l_2} (s - l_2) = -a_2 \frac{l_2 - s}{l_2}.$$

Therefore the triangle  $DBL$  is the influence diagram for  $W_2 a_2 \frac{l_2 - s}{l_2}$ , where  $W_2 = 1$ . Combining this with the *base diagram*, the shaded figure  $EFBL$  is obtained as the influence diagram for loads in this span.

For loads in the suspended span the influence diagram is the shaded area  $BLM$ .

The criterion for wheel loads producing the maximum moment is found as follows:

Without stating the intermediate equations

$$\frac{\delta M_s}{\delta x} = W_2 \left\{ -\frac{s-b}{d} + 1 \right\} + W_2' \left\{ 1 \right\} + W_3 \left\{ \frac{s-l_2}{l_3} \right\} = 0, \quad (78)$$

or

$$\frac{W_2}{d} = \frac{W_2'}{s-b-d} + \frac{W_3}{s-b-d} \frac{s-l_2}{l_3}. \quad \cdot \cdot \cdot \quad (79)$$

If  $s - l_2 = l_3$ ,

$$\frac{W_2}{d} = \frac{W_2' + W_3}{s-b-d}. \quad \cdot \cdot \cdot \quad (80)$$

#### CONTINUOUS AND PARTIALLY CONTINUOUS TRUSSES OF TWO EQUAL SPANS

**Partially Continuous Truss.**—In Fig. 34 is shown a common form of the revolving draw-bridge. The two end spans are equal and are separated by an unbraced



short span over the turntable. The moments  $M_2$  and  $M_3$  over the turntable are assumed equal and, for convenience, their values are determined as if the truss was a beam of constant cross-section. In any case the values of  $M_2$  and  $M_3$  can be found by a more rigid method, if desired, without increasing the labor of constructing the influence diagrams.

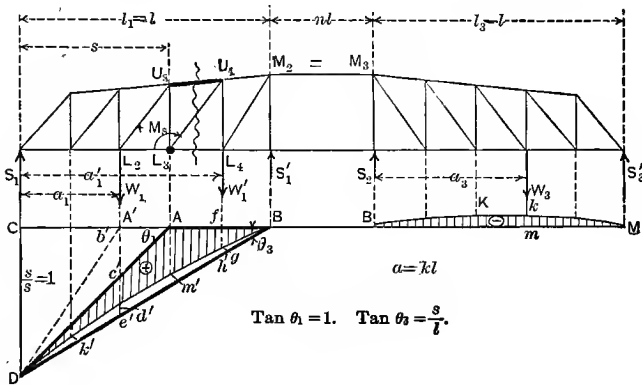


FIG. 34.

**Top Chord of a Partially Continuous Truss.**—Referring to Fig. 34, the top chord  $U_3U_4$  has its center of moments at  $L_3$ . For loads in this span,

$$M_L = 0 \quad \text{and} \quad M_R = M_2,$$

but

$$M_2 = -W_1 l_1 \frac{k_1 - k_1^3}{4 + 6n},$$

where

$$k_1 = \frac{a_1}{l_1}.$$

Therefore, from equation (d),

$$M_s = -W_1 l_1 \frac{k_1 - k_1^3}{4 + 6n} \frac{s}{l_1} + m_s. \quad . \quad . \quad . \quad (81)$$

Dividing through by  $s$ ,

$$\frac{M_s}{s} = -W_1 \frac{k_1 - k_1^3}{4 + 6n} + \frac{m_s}{s}. \quad . \quad . \quad . \quad (82)$$

The influence diagram for  $\frac{m_s}{s}$  is represented by the *base diagram* drawn with  $CD=1$ . This is shown in Fig. 34 by the heavy line triangle.

The value of  $\frac{k_1 - k_1^3}{4 + 6n}$  is now computed for the positions of  $W_1$ =unity, corresponding to the panel points of the truss. In the truss shown  $k_1$  has the values 0, 1/5, 2/5, 3/5, 4/5, and 1. The corresponding values of  $\frac{k_1 - k_1^3}{4 + 6n}$  are laid off as ordinates above the line  $DB$  directly below the panel points and the ends of the ordinates connected by straight lines forming the polygon  $Dk'd'm'gB$ . The influence diagram for  $\frac{M_s}{s}$  is the shaded area shown in the figure. To obtain the value of  $M_s$  for any particular load the corresponding ordinate in the influence diagram is multiplied by  $s$ .

For any other center of moments as  $L_2$  it is only necessary to draw one straight line as  $DA'$  to obtain the influence diagram.

In case the center of moments lies in a field covering about one-fifth the span  $l_1$ , adjacent to the turntable, the line  $DA$  will cut the polygon  $Dd'B$  and thereby indicate

the fields of loading in this span which produce moments of opposite character.

The position of wheel loads producing the maximum moment is best found by trial.

For loads in the third span

$$M_L = 0, \quad M_R = -W_3 l_3 \frac{2k_3 - 3k_3^2 + k_3^3}{4 + 6n}, \quad m_s = 0,$$

and

$$M_s = -W_3 l_3 \frac{2k_3 - 3k_3^2 + k_3^3}{4 + 6n} \frac{s}{l_1}. \quad \dots \quad (83)$$

Remembering that  $l_1 = l_3 = l$  and dividing through by  $s$ ,

$$\frac{M_s}{s} = -W_3 \frac{2k_3 - 3k_3^2 + k_3^3}{4 + 6n}. \quad \dots \quad (84)$$

The influence diagram corresponding to this expression is shown by the shaded area *BKM*, Fig. 34.

The position of wheel loads producing the maximum moment is found by trial. This position when found will remain constant for all centers of moments in the first span.

VALUES OF  $\frac{k - k^3}{4}$

Unit Load at	NUMBER OF PANELS IN SPAN.					
	4	5	6	7	8	9
$L_1$	.0586	.048	.0406	.0350	.0308	.0274
$L_2$	.0938	.084	.0740	.0656	.0586	.0527
$L_3$	.0820	.096	.0937	.0874	.0806	.0740
$L_4$		.072	.0925	.0962	.0938	.0891
$L_5$			.0637	.0875	.0952	.0960
$L_6$				.0568	.0820	.0925
$L_7$					.0513	.0767
$L_8$						.0466

The above table contains the values of  $\frac{k-k^3}{4}$  for unit loads placed at the panel points of trusses having from four to nine panels. These values multiplied by  $\frac{4}{4+6n}$  give the ordinates represented by  $\frac{k-k^3}{4+6n}$ . If the ordinates in any particular case are laid off in an inverse order the resulting polygon will represent the expression  $\frac{2k-3k^2+k^3}{4+6n}$ .

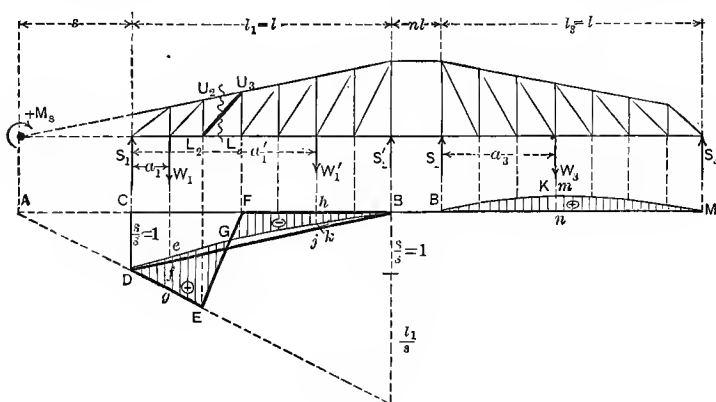


FIG. 35.

**Diagonal of a Partially Continuous Truss.**—The diagonal  $L_2U_3$  in Fig. 35 has its center of moments at the intersection of  $U_2U_3$  and  $L_2L_3$ . Since the point of intersection lies upon the left of the left end of the span,  $s$  is negative.

For loads in this span,

$$M_L = 0, \quad M_R = -W_1 l_1 \frac{k-k^3}{4+6n},$$

and

$$\frac{I_s}{s} = W_1 \frac{k_1 - k_1^3}{4+6n} + \frac{m_s}{s} \quad \dots \quad (85)$$

The influence diagram for  $\frac{m_s}{s}$  is indicated by the heavy lines in Fig. 35. This is the *base diagram* with  $CD = \text{unity}$ . The ordinates represented by the expression  $\frac{k_1 - k_1^3}{4 + 6n}$  are laid off above the line  $DB$ . The influence diagram for  $\frac{M_s}{s}$  is the shaded area  $DEGFB$ . For any other diagonal the lines  $DE$  and  $EF$ , only are changed.

The position of wheel loads producing the maximum moment is found by trial. This is easily done as the influence areas are nearly triangular in form.

For loads in the third span,

$$M_L = 0, \quad M_R = -W_3 l_3 \frac{2k_3 - 3k_3^2 + k_3^3}{4 + 6n}, \quad m_s = 0,$$

and

$$\frac{M_s}{s} = W_3 \frac{2k_3 - 3k_3^2 + k_3^3}{4 + 6n}. \quad . \quad . \quad . \quad (86)$$

The influence diagram is indicated by the shaded area  $BKM$ .

As before, the position of wheel loads is found by trial.

**Continuous Truss of Two Equal Spans.**—If there is no short span over the turntable  $n = 0$  and the only changes in the influence diagrams given above will be the ordinates to the polygonal figures. These will be increased in the ratio of  $4 + 6n$  to 4.

## CHAPTER IV

### ARCHES

Arches with open webs and with solid webs will be considered. The three-hinged and the two-hinged arch can be handled with but little labor. The influence diagrams for fixed arches are complicated and are best constructed from computed ordinates.

Equation (d) is now modified by the moment of the horizontal thrust. If the lever arm of the horizontal thrust,  $H$ , is represented by  $y$ , then

$$M_s = M_L \frac{l-s}{s} + M_R \frac{s}{l} - Hy + m_s. \quad . \quad . \quad . \quad (e)$$

**Diagonals in a Three-hinged Arch with Open Web.**—The frame diagram of a three-hinged arch is shown in Fig. 36 and the influence diagrams for the diagonals  $U_2L_3$  and  $U_3L_4$  are outlined in Figs. 36a and 36b.

Since there can be no bending moments at the hinges over the supports,  $M_L$  and  $M_R$  in equation (e) are zero, and

$$\frac{M_s}{y} = -H + \frac{m_s}{y}. \quad . \quad . \quad . \quad . \quad . \quad (87)$$

The influence diagram for  $\frac{m_s}{y}$  is the *base diagram* con-

structed with  $CD = \frac{s}{y}$ . This is shown by the area surrounded by heavy lines in Fig. 36a.

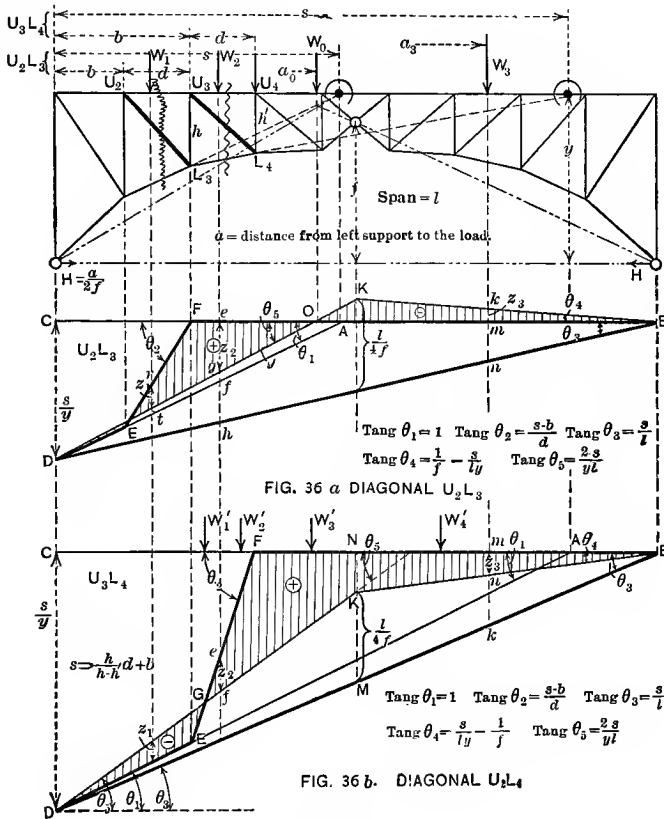


FIG. 36.

The expression for  $H$  is

$$H = W \frac{a}{2f}.$$

This indicates that  $H$  varies directly as the distances of the load from the supports and hence the influence diagram

for  $H$  will be a triangle between the support and the center hinge. Placing a unit load at the center hinge,

$$H = \frac{l}{4f}.$$

Lay off this distance above  $DB$  directly below the center hinge and thus locate the point  $K$ . Draw  $KD$  and  $KB$ ; then the shaded area is the influence diagram for  $\frac{M_s}{y}$  corresponding to the diagonal  $U_2L_3$ . Fig. 36b is a similar diagram for the diagonal  $U_3L_4$ .

For chord members the same method is employed. The triangle  $DKB$  is constant for all influence diagrams.

The position of wheel loads producing the maximum moment is best found by trial as some of the criterions become too complex for easy application.

To illustrate the shape of one criterion, consider the influence diagram in Fig. 36b in deriving a criterion for the diagonal  $U_3L_4$ .

$$\begin{aligned} \frac{\delta M_s}{\delta x} = & -W_1'(-\tan \theta_5 + \tan \theta_2) + W_2'(+\tan \theta_5 - \tan \theta_2) \\ & + W_3' \tan \theta_5 + W_4' \tan \theta_4 = 0, \quad (88) \end{aligned}$$

or

$$\begin{aligned} (W_1' + W_2' + W_3') \tan \theta_5 - (W_1' + W_2') \tan \theta_2 \\ + W_4' \tan \theta_4 = 0. \quad (89) \end{aligned}$$

Substituting the values of the tangents

$$(W_1' + W_2' + W_3') \frac{2s}{ly} = (W_1' + W_2') \frac{s-b}{d} - W_4' \left( \frac{s}{ly} - \frac{1}{f} \right). \quad (90)$$



**Chord of Two-hinged Arch with Open Web.**—As in the case of the three-hinged arch the moments  $M_L$  and  $M_R$  are zero, and

$$\frac{M_s}{y} = -H + \frac{m_s}{y} \dots \dots \dots (91)$$

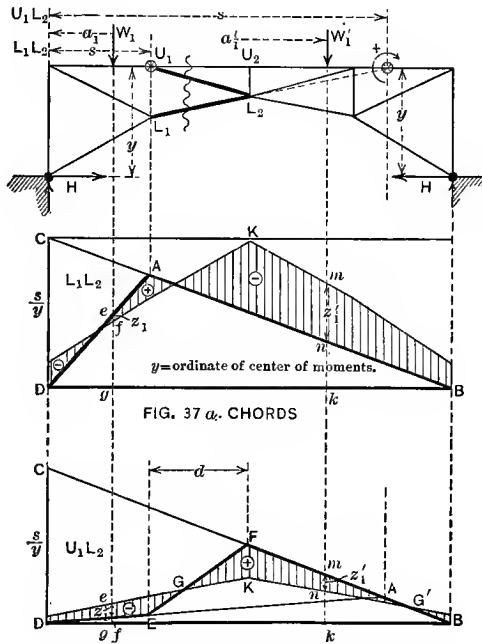


FIG. 37 b. WEB MEMBERS

FIG. 37.

The influence diagram for  $\frac{m_s}{y}$  is the *base diagram* drawn with  $CD$  equal  $\frac{s}{y}$ . This is indicated by heavy lines in Fig. 37a. The values of  $H$  for a unit load at each panel point of the loaded chord are computed and laid off above  $DB$  and the upper ends connected by straight lines. The



The position of wheel loads producing the maximum moment is found by trial.

**Moment Influence Diagram for Two-hinged Arch with Solid Web.**—For the solid arch the influence diagram is quite simple as it is made up of the combination of the *base diagram* and the diagram for  $H$ , corresponding to unit loads, which is a smooth curve. The moment influence diagram is shown by the shaded area in Fig. 38*a*. For any other center of moments than the one indicated it is necessary to change only the lines  $CB$  and  $DA$ .

**Vertical Shear for Two-hinged Arch with Solid Web.**—The influence diagram for vertical shear is the same as explained for simple trusses on two supports by making the length of the cut stringer zero so that  $E$  and  $F$  of the *base diagram* lie in the same vertical line. This diagram is shown in Fig. 38*b*.

## CHAPTER V

### BEAMS OF CONSTANT CROSS-SECTION

**The Influence Diagrams** for beams are but little different from those which have been explained. In all cases the final diagram can be constructed upon the base diagram.

**Restrained Beams.**—Referring to Fig. 39, the moment at any section  $X$  is given by equation (d) or

$$M_s = M_R \frac{l-s}{l} + M_L \frac{s}{l} + m_s. \quad . \quad . \quad . \quad (d)$$

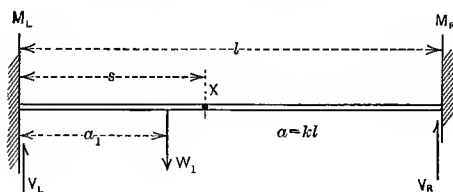


FIG. 39.

If the vertical shear at the section  $X$  is represented by  $S_s$ ,

$$S_s = V_L - \sum_{s > a} W = \frac{M_R - M_L}{l} + R_1 - \sum_{s > a} W. \quad . \quad (92)$$

But  $R_1 - \sum_{s > a} W = S$  = the vertical shear for a simple beam resting upon two supports; therefore

$$S_s = \frac{M_R - M_L}{l} + S. \quad . \quad . \quad . \quad . \quad (f)$$

**Simple Beam on Two Supports.**—For a simple beam resting upon two supports  $M_L$  and  $M_R$  are zero, hence

$$M_s = m_s \quad \text{and} \quad S_s = S.$$

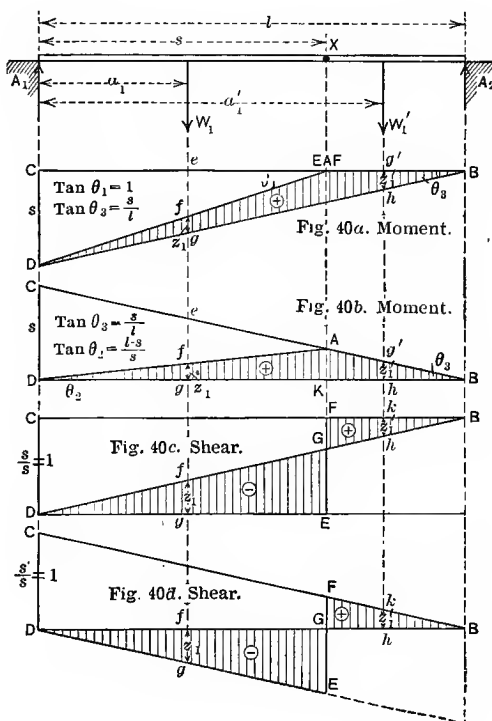


FIG. 40.

The influence diagrams for  $m_s$  and  $S$  are *base diagrams* constructed according to the general rule. Figs. 40a and 40b show moment influence diagrams. In one diagram  $CB$  is drawn horizontal according to rule, while in the other  $DB$  is horizontal. Evidently the ordinates are the same in both figures.

The influence diagrams for  $S$  are shown in Figs. 40c and 40d.

The criterion for wheel loads which produce the maximum moment is

$$\frac{W_1}{s} = \frac{W_1'}{l-s} \cdot \cdot \cdot \cdot \cdot \cdot (93)$$

**Beam Fixed at One End and Supported at the Other End.—**

In this case referring to Fig. 41,  $M_L = 0$ ,  $M_R = -Wl \frac{k-k^3}{2}$ ,

and

$$\frac{M_s}{s} = -W \frac{k-k^3}{2} + \frac{m_s}{s} \cdot \cdot \cdot \cdot \cdot (94)$$

The influence diagram for  $\frac{m_s}{s}$  is the *base diagram* drawn with  $CD = \text{unity}$  as shown by the heavy lines in Fig. 41a. The influence diagram for  $\frac{k-k^3}{2}$  is the figure  $DGBD$  and the influence diagram for  $\frac{M_s}{s}$  is the shaded area. For any other center of moments the only line changed is  $DA$ .  
For vertical shear

$$S_s = -W \frac{k-k^3}{2} + S \cdot \cdot \cdot \cdot \cdot (95)$$

The influence diagram for  $S$  is shown by the heavy lines in Fig. 41b. The curve representing  $\frac{k-k^3}{2}$  is drawn above  $DB$  and then the shaded area is the influence diagram for  $S_s$ .

**Beam Fixed at Both Ends.**—In this case,

$$M_L = -Wl(k - 2k^2 + k^3), \quad M_R = -Wl(k^2 - k^3),$$

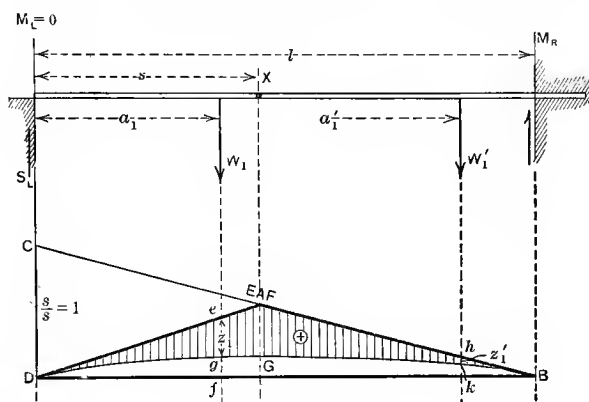


FIG. 41 a. MOMENTS

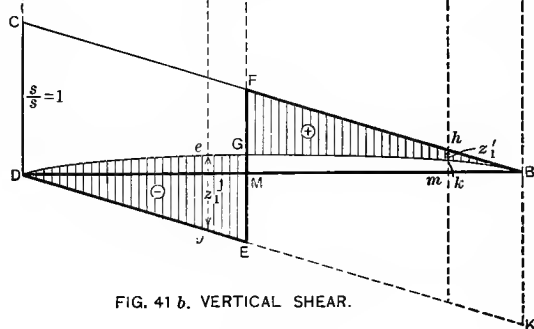


FIG. 41 b. VERTICAL SHEAR.

FIG. 41.

and

$$M_s = -Wl(k - 2k^2 + k^3) \frac{l-s}{l} - Wl(k^2 - k^3) \frac{s}{l} + m_s,$$

or

$$\frac{M_s}{s} = -W(k - 2k^2 + k^3) \frac{l-s}{l} - W(k^2 - k^3) + \frac{m_s}{s}. \quad (96)$$

The *base diagram* indicated by the heavy lines in Fig. 42a, is the influence diagram for  $\frac{m_s}{s}$ . The ordinates to

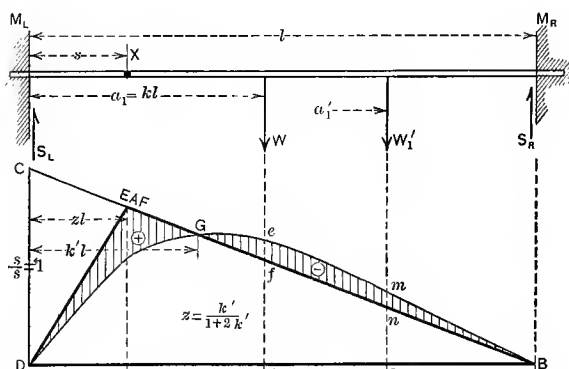


FIG. 42 a. MOMENTS

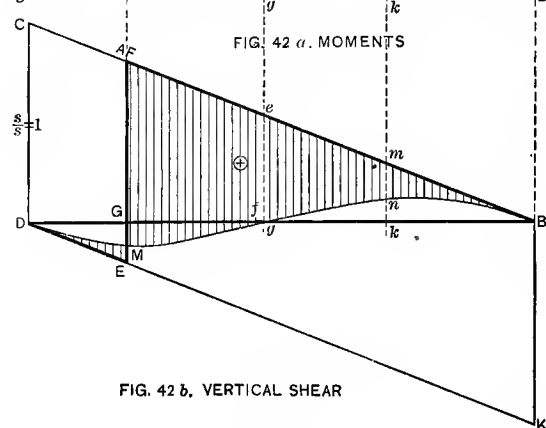


FIG. 42 b. VERTICAL SHEAR

FIG. 42.

the curve  $DGB$  are obtained by giving  $k$  corresponding values in the expression

$$-(k - 2k^2 + k^3) \frac{l-s}{l} - (k^2 - k^3).$$

Then the shaded area is the influence diagram for  $\frac{M_s}{s}$ .



For vertical shear

$$S_s = W(k - 3k^2 + 2k^3) + S. \quad . \quad . \quad . \quad (97)$$

The shaded area in Fig. 42*b* is the influence diagram for  $S_s$ .

VALUES OF  $k^2 - k^3$  AND  $k - 2k^2 + k^3$

$k$	$k^2 - k^3$		$k$	$k^2 - k^3$	
0	0	1.00			
.05	.002375	.95	.50	.125000	.50
.10	.009000	.90	.55	.136125	.45
.15	.019125	.85	.60	.144000	.40
.20	.032000	.80	.65	.147875	.35
.25	.046875	.75	.70	.147000	.30
.30	.063000	.70	.75	.140625	.25
.35	.079625	.65	.80	.128000	.20
.40	.096000	.60	.85	.108375	.15
.45	.111375	.55	.90	.081000	.10
.50	.125000	.50	.95	.045125	.05
			1.00	0	0
	$k - 2k^2 + k^3$	$k$		$k - 2k^2 + k^3$	$k$
$k - 3k^2 + 2k^3 = (k - 2k^2 + k^3) - (k^2 - k^3)$					



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